Kapsch® TrafficCom IVHS Inc.

ACTIVE TDM OVER-AIR SPECIFICATION FOR ELECTRONIC TOLL COMMUNICATIONS

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This specification only covers over-air inter-operable characteristics, not a complete specification. Conformance to material hereunder is not sufficient to prove fit for purpose and agencies will likely require performance testing in intended application(s).

Agencies likely will require certain articles to be signed by prospective suppliers of devices conformant to this specification. An exhibit is provided in Appendix 2 to this document that outlines the minimum that such agencies should include.

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Table of Contents

1. INTRODUCTION ... 7
1.1 REFERENCE SYSTEM AND PROTOCOL OVERVIEW ... 7
1.2 REFERENCE DOCUMENTS ... 9
1.3 TERMS, DEFINITIONS, ACRONYMS, ABBREVIATIONS ... 9
1.3.1 Acronyms and Abbreviations ... 10
1.3.2 Terms and Definitions ... 10
1.3.3 Requirement conventions ... 11
1.3.4 Numeric Conventions ... 11
1.3.5 RF Modulation Characteristics ... 12
1.3.6 OOK Manchester ... 13
1.3.7 OOK Beacon ... 14

2. PHYSICAL LAYER SPECIFICATIONS ... 15
2.1 GENERIC REQUIREMENTS ... 15
2.2 SPECTRUM REGULATORY REQUIREMENTS ... 15
2.3 FREQUENCY ... 15
2.4 POLARIZATION ... 15
2.5 SENSITIVITY ... 15
2.6 RADIATED POWER ... 16
2.7 TRANSMISSION TIMING ... 16
2.8 TRANSMISSIONS ... 17
2.9 MODULATION ... 17
2.9.1 Trigger Pulse Modulation ... 18
2.9.1 Beacon Modulation ... 18
2.9.2 Transponder Data Modulation ... 18
2.9.3 Program Data Modulation ... 19

3. DATA LAYER SPECIFICATIONS ... 20
3.1 BEACON ... 20
3.2 TRANSPONDER DATA ... 21
3.2.1 Factory Fixed ... 21
3.2.2 Agency Fixed ... 22
3.2.1 Reader Programmable ... 22
3.2.2 CRC ... 23
3.3 PROGRAM RULES ... 24

4. APPENDIX 1: TAG TYPE DEFINITIONS AND SPECIFIC REQUIREMENTS ... 25

5. APPENDIX 2: EXHIBIT OF MINIMUM ARTICLES TO BE REQUIRED BY AGENCIES OR GROUPS AND ACCEPTED BY SUPPLIERS FOR SUPPLY OF PRODUCT CONFORMANT TO THIS SPECIFICATION ... 27

List of Figures

Figure 1-1: Generic System Example 8
Figure 1-2: Generic Transaction Sequence 8
Figure 1-3: RF Event Time Sequence 9
Figure 1-5: Intra-Burst and Pulse Definitions 13

List of Tables

Table 2-1: Trigger Modulation 18
Table 2-2: Beacon Modulation 18
Table 2-3: Transponder Data Modulation 18
Table 2-4: Program Data Modulation 19
Table 3-1: Tag Type 22
Table 3-2: Application ID 22
Table 3-3: HOV & Feedback 23
Table 4-1: Specific Windshield Transponder Categorization 25
Table 4-2: Sensitivity and Radiated Power Requirements at Vehicle 26

1. INTRODUCTION

This Active TDM Over-Air Specification for Electronic Toll Communications (Specification) defines a Time Division Multiplex (TDM) protocol and other requirements for communicating with listen-before-talk active (self-powered) transponders that are mounted on vehicles for the purpose of automatic vehicle monitoring and identification in the non multilateration portion of the 902-928 MHz Location and Monitoring service band. The protocol is intended primarily for the purpose of electronic toll collection, but may also be used for other intelligent transportation applications requiring high performance, location based, automatic identification of (moving) vehicles via electronic means.

This Specification documents the method of communication between readers and vehicle mounted transponders commonly referred to as either On Board Units (OBUs) or tags. The Specification covers the minimum physical and logical layers of the protocol and other requirements necessary for interoperable communications between readers and transponders. It does not provide the application specific data content for the applications using the protocol, nor does it specify the means of storing application specific fixed data content within transponders.

1.1 Reference System and Protocol Overview

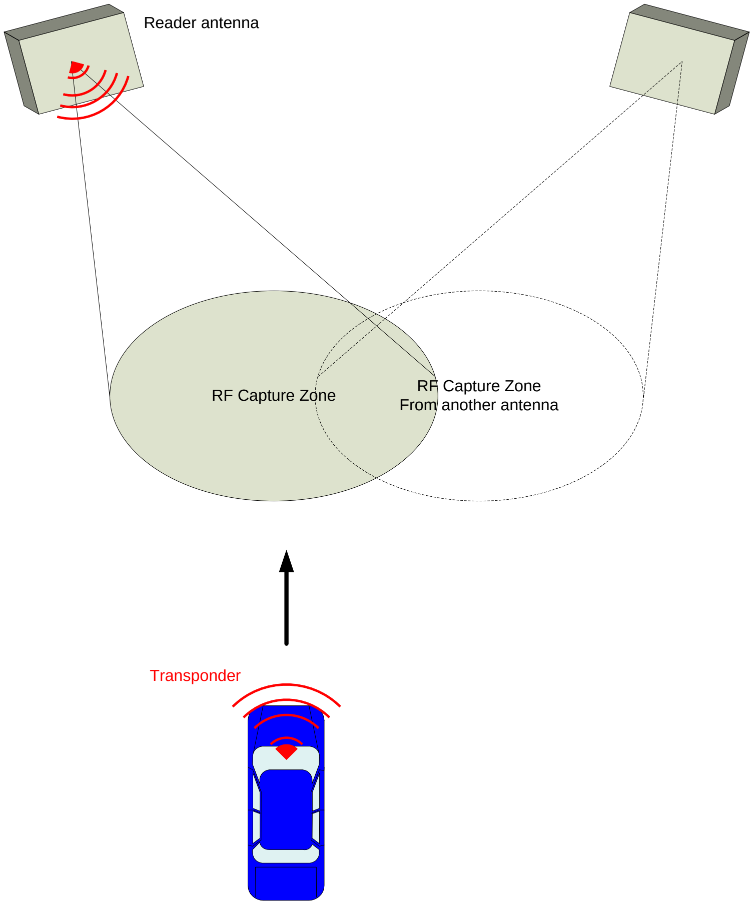
Figure 1-1 below shows the block diagram of key aspects of a typical automatic vehicle monitoring or identification system embodying this protocol.

Each transponder is mounted on a vehicle at a location that is visible to a reader antenna. It becomes visible when the vehicle passes through the radio frequency (RF) capture zone for that antenna, which is dictated by the directional pattern of the reader antenna, the transmit power of the reader, and the expected sensitivity of the transponders including the directional pattern of the transponder antenna along with characteristics of the vehicle to which it is mounted   A reader may support more than one antenna all operating at the same radio frequency range and these may be used to create overlapping RF capture zones without mutual radio interference.

The reader emits trigger pulses from its antennas. These trigger pulses are time multiplexed such that a transponder will be presented with one trigger pulse at a time and be able to complete a response to the reader before another trigger is received.

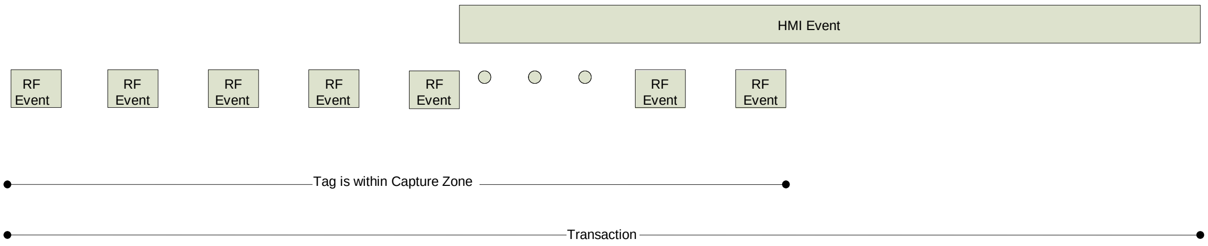
When a transponder enters the RF capture zone of a reader antenna and the received trigger level exceeds the transponder’s sensitivity threshold then the transponder transmits its stored data to the reader. While the transponder remains in the RF capture zone it will continue to receive triggers and respond to them.

Figure 1-1: Generic System Example



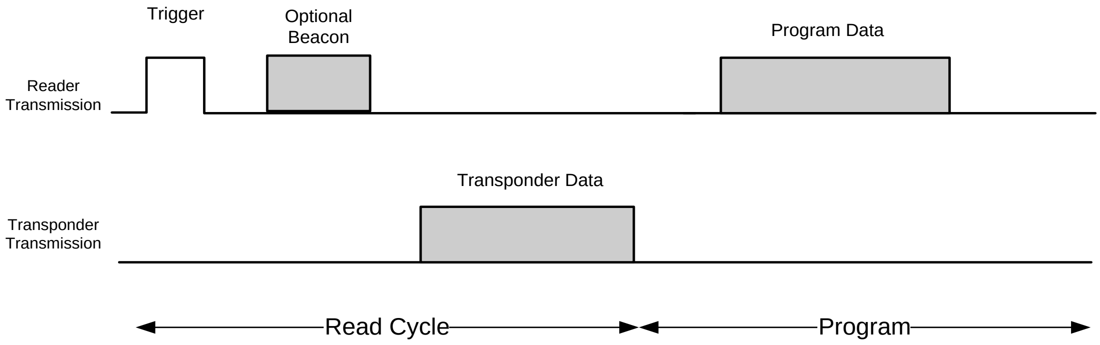
The complete passage of the transponder through the RF capture zone(s) of a reader results in a transaction sequence of discrete RF events (protocol cycles). Some transponders provide driver feedback (human- machine interface (HMI)) under reader control. The generic transaction sequence is shown in Figure 1-2.

Figure 1-2: Generic Transaction Sequence



For each RF event depicted in Figure 1-2 the sequence is nominally as shown in Figure 1-3. The reader activates the transponder for the event by transmitting a trigger pulse of carrier. When the transponder detects a trigger pulse it responds by sending the data from its internal memory back to the reader. This constitutes a Read cycle.

Figure 1-3: RF Event Time Sequence



The reader accesses the transponder memory as a single 256 bit data structure, which is subdivided into:

- A fixed data section reserved for use by manufacturer
- A fixed data section reserved for use by transponder issuing agency
- A programmable data section that can be changed using the protocol defined herein, and
- A cyclic redundancy checksum (CRC) computed for the data structure.

After transmitting its internal data the transponder monitors the downlink path from the reader for possible program data. If program data is detected as having been sent by the reader and this data is validated as defined herein, the transponder will store the received data in its internal memory, overwriting prior data, such that on subsequent triggers the transponder will transmit the new data.

The sequence of Read cycle plus program is also referred to as a Read-Program (RP) cycle.

Some readers and transponders can support an optional beacon transmitted by the reader after the trigger but prior to the expected transponder response to the trigger. Transponders not designed to use the beacon data ignore the beacon if present and the read and program operations are not affected by the beacon presence or absence.

1.2 Reference Documents

The following references herein apply to equipment conforming to this Specification.

- Title 47 Code of Federal Regulations (CFR) Part 90, Subpart M - Intelligent Transportation Systems Radio Service
- Radio Standards Specification RSS-137, Location and Monitoring Service (902-928 MHz)
- SAE J1211, Recommended Environmental Practice for Electronic Equipment Design, NOV 1978

1.3 Terms, Definitions, Acronyms, Abbreviations

For the purposes of this Specification, the following terms, definitions, acronyms and abbreviation apply.

1.3.1 Acronyms and Abbreviations

CFR	Code of Federal Regulations
CRC	cyclic redundancy checksum
EIRP	effective isotropic radiated power
HMI	Human Machine Interface, i.e. audio or visual feedback by a transponder
HOT	high occupancy toll
HOV	high occupancy vehicle
LSB	least significant bit
max	maximum
min	minimum
MSB	most significant bit
nom	nominal
OBU	On Board Unit
OOK	On-Off Keying
RF	radio frequency
RFU	reserved for future use
RP	Read-Program (cycle)
TDM	time division multiplex

1.3.2 Terms and Definitions

Antenna: A RF radiating structure that produces a single principal lobe transmission radiation pattern. If an implementation uses a radiating structure that produces multiple transmitting principal lobes or selectable principal lobes, then within the content of this document each lobe is considered as belonging to a different antenna.

Agency: A body or organization for which transponders are manufactured and with and by which transponders are associated and managed during their life. The Agency is responsible for transponder Serial Number (see Section 3.2.1) assignment, programming of the Fixed Agency content in transponder memory (see Section 3.2.2) and transponder management including transponder validity.

Agency ID: A data field which is stored in the transponder memory by the manufacturer and is used in the Transponder Data structure transmitted by this protocol. The data field identifies the Agency within the Group to which the transponder is associated.

Beacon: A data transmission from a reader to transponders occurring between the trigger and the transponder response.

Burst Peak Power: The maximum emitted RF power over a trigger pulse or a burst transmission and is used herein as a reference for defining specifications of other burst and pulse characteristics.

Group: An assigned grouping of Agencies that use common transponder application data structure and whose transponders are directly inter-operable at all layers. A Group could be a formal organization of Agencies, or a geo-political jurisdiction, e.g. a state, or a market segment. A contact organization will exist for each Group.

Group ID: A data field that is stored in the transponder memory by the manufacturer and is used in the Transponder Data structure transmitted by this protocol. The data field identifies the Group to which the transponder is associated.

Program: The operation of the reader transmitting data to the transponder and the transponder updating its memory with the new data.

Read: The operation of the reader transmitting a Trigger to the transponder and the transponder replying by transmitting its memory content.

RF Capture Zone: The three-dimensional volumetric space associated with the transmissions from a reader's antenna within which a transponder meeting the sensitivity requirements would be expected to respond to trigger pulses and outside of which the transponder would be expected not to respond.

RF Event: An instance of exchange of information between a reader and a transponder comprising a Trigger and a Transponder Data transmission and, if present, a Beacon and/or a Program Data transmission, as exemplified by Figure 1-3.

Serial Number: A transponder identification number that is stored in the transponder memory by the manufacturer. The Serial Number is assigned by the Agency associated with the transponder. In combination with the Group ID and Agency ID, the Serial Number is intended to be unique over all instances of transponders conformant to this protocol.

Sensitivity: The RF field strength for the trigger pulse and for the ON condition in the ON-OFF Keyed modulation at which a transponder should respond to a trigger and at which it can decode the beacon and program data.

Trigger: A pulse transmission from a reader that initiates each RF Event.

1.3.3 Requirement conventions

This Specification uses the following interpretations for requirements and conformance:

- A statement using the word "shall" defines a mandatory requirement that must be satisfied to claim conformance.
- A statement using the word "should" defines a preferred requirement but not one that has to be satisfied to claim conformance.
- A requirement defined as "optional" means that it is not necessary to provide this feature to claim conformance. However if the optional feature is provided, all subordinate requirements must be satisfied to claim conformance.

1.3.4 Numeric Conventions

Within this Specification all numeric values are expressed in decimal notation except where explicitly stated otherwise as listed below.

For numbers expressed in binary notation the format xxx_B is used where xxx represents a sequence of binary digits and the binary digits are presented in order from most significant to least significant.

For numbers expressed in hexadecimal notation the format xxx_H is used where xxx represents a sequence of hexadecimal characters and the characters are presented in order from most significant to least significant.

Bit and character numbering within a word or data field within this document uses the convention that increasing value indicates increasing significance and numbering starts with the value 0. Thus for example for an 8-bit field bit 0 would be the least significant bit (LSB) and bit 7 would be the most significant bit (MSB).

For numerical operations the multiply operation is indicated by * and the division operation by /. Thus an expression 8 * N would indicate a value of 8 times N, while an expression N / 8 would indicate a value of N divided by 8.

For repeating digits the digits that repeat are identified by overline, e.g 0.3333… would be represented by $0.\overline{3}$.

1.3.5 RF Modulation Characteristics

The RF modulation characteristics herein are specified as emitted by the transmitter. Effects of propagation and other system effects are application specific and are not included herein. The following defines the parameters specified herein.

The modulation used in this protocol is ON-OFF Keyed (OOK) amplitude modulation.

A burst RF transmission can be described as shown in Figure 1-4. The parameters defined by that figure are:

Burst Peak Power	is the peak value of power radiated by the transmitter over a transmission burst, i.e. the maximum ON power in OOK modulation over the burst.
Burst Flatness	is the variation in the peak value of the ON power over all instances of ON during a burst.
OFF Isolation	is the ratio of the unwanted power radiated by the transmitter outside the transmission burst relative to the Burst Peak Power.

The pulse characteristics within a burst are described with reference to Figure 1-5. The parameters defined by that figure are referenced to Ideal ON and Ideal OFF time that are the theoretical pulse widths computed at the Ideal Bit Rate for the transmission. The parameters specified that are related to the definitions of that figure are:

Modulation Width Variation	constrains the modulation pulse and gap timing limits (Min ON Time, Max ON Time, Min OFF Time, and Max OFF Time). It is expressed as the maximum allowed deviation of the pulse and gap widths from the ideal values (Ideal ON Time and Ideal OFF Time) over the specified range of Modulation Depth.
Pulse Flatness	is the allowed variation between the peak amplitude of the pulse and the amplitude at which it meets the Min ON Time
Modulation Depth	is the minimum required suppression of the RF for the OFF condition relative to the RF amplitude at the point the pulse meets the MIN ON Time.

The Bit Rate Tolerance used later herein is the allowed deviation from the Ideal Bit Rate over the burst. This parameter controls gradual or systematic variation along the burst, for example caused by quantization or errors in the timing generation of the transmitter. Each sample of bit rate along the burst shall be measured between similar bit edges (e.g. rising edges at beginning of the bit period) with spacing no greater than 20 bit periods apart.

Figure 1-4: Burst Definitions

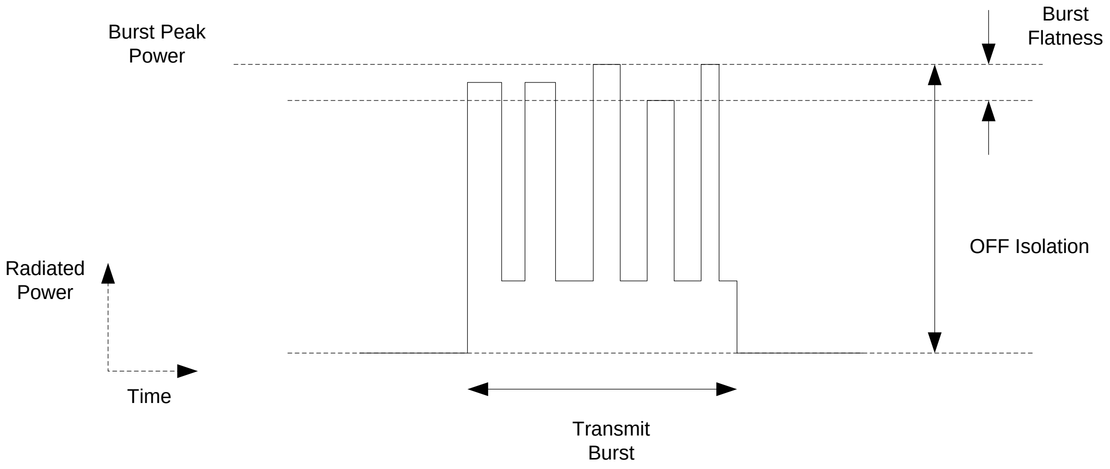
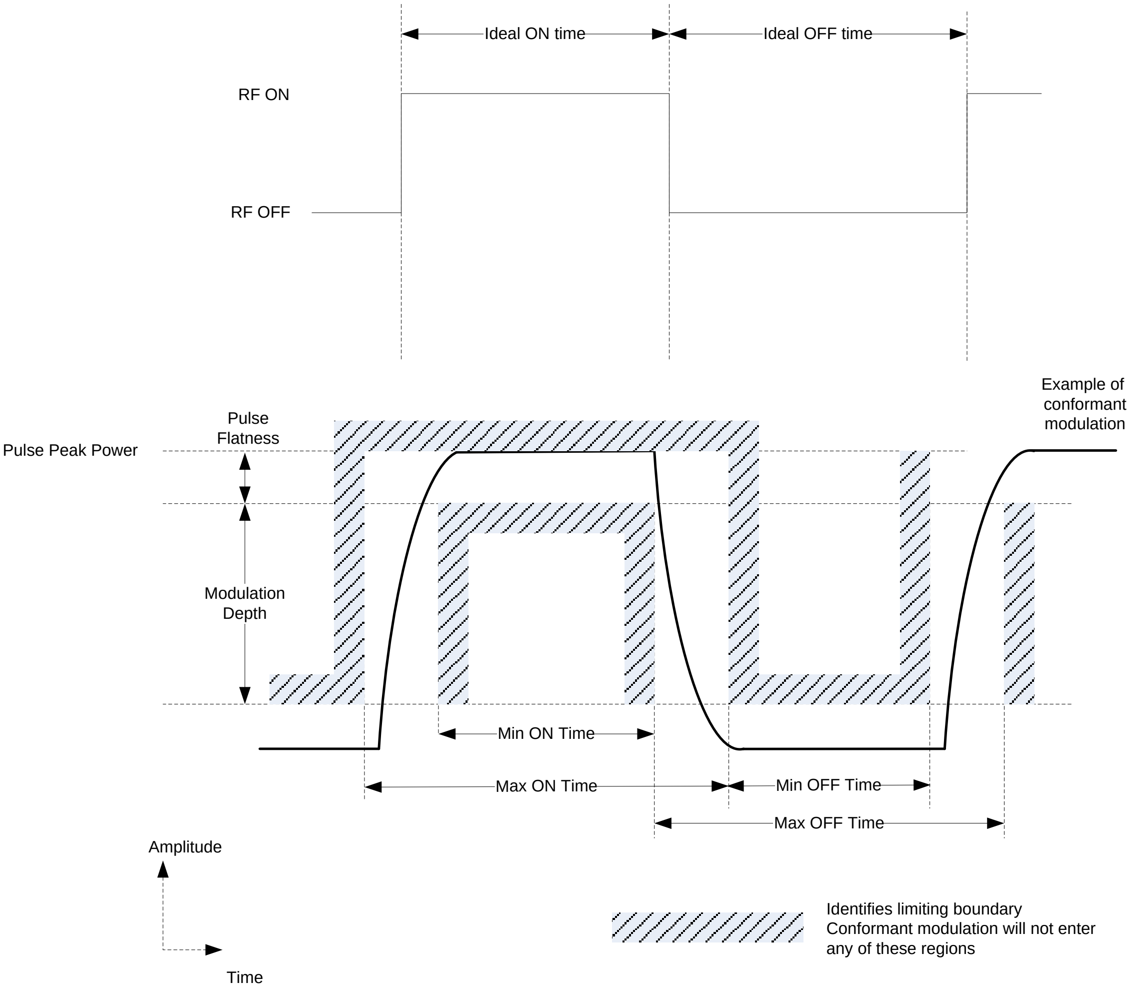


Figure 1-5: Intra-Burst and Pulse Definitions



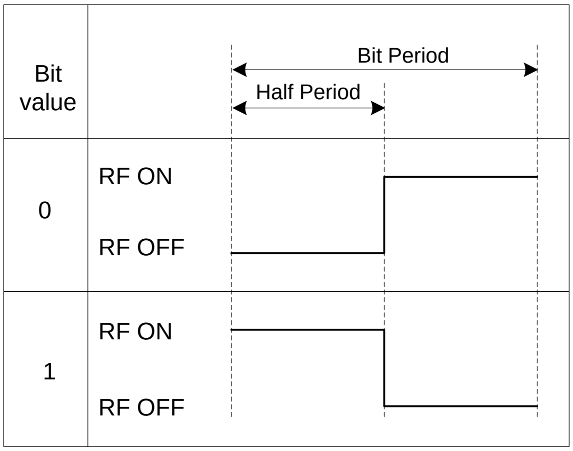
1.3.6 OOK Manchester

Some transmissions herein are specified to use OOK Manchester modulation. For each bit to be transmitted the transmitter ideally emits the RF for 50% of the bit period in accordance with Figure 1-6.

Where the RF was in the ON condition at the end of a bit and is required to be in the ON condition at the start of the next bit, there is no interruption of the RF at the transition between bits. Over multiple bits the Ideal ON time can take the values 0.5 and 1.0 bit periods. Similarly the Ideal OFF time can take the values 0.5 and 1.0 bit periods.

The RF is in the OFF state prior to a data burst and returns to the OFF state at the end of the burst.

Figure 1-6: OOK Manchester



1.3.7 OOK Beacon

The Beacon uses a specific version of OOK coding defined by Figure 1-7, referred to herein as OOK Beacon.

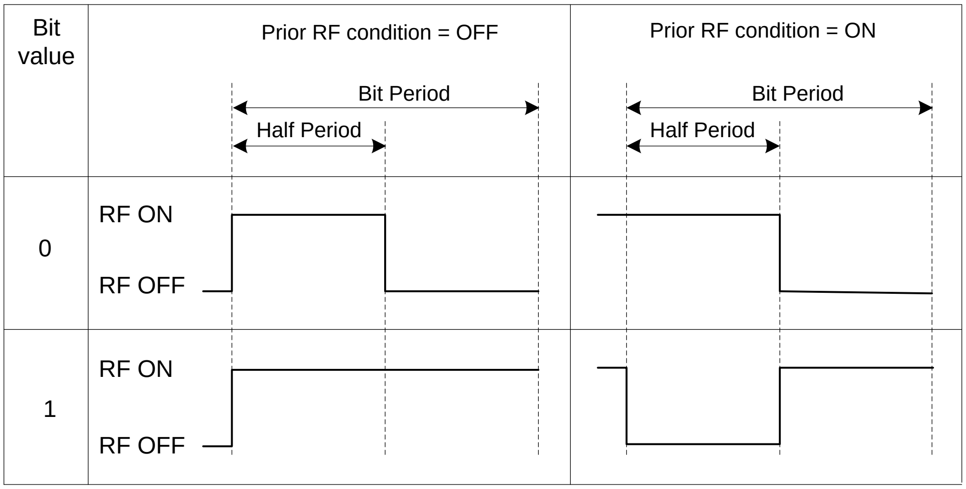
The modulation coding of a bit is dependent on the condition of the RF immediately prior to the bit as shown in the figure.

Where the RF was in the ON condition at the end of a bit and is required to be in the ON condition at the start of the next bit, there is no interruption of the RF at the transition between bits.

Over multiple bits the Ideal ON time can take the values 0.5, 1.0 and 1.5 bit periods. The Ideal OFF time is always 0.5 bit periods.

The RF is in the OFF state prior to a burst and returns to the OFF state at the end of the burst.

Figure 1-7: OOK Beacon



2. PHYSICAL LAYER SPECIFICATIONS

2.1 Generic Requirements

All time parameters of over-the-air transmissions from readers stated as nominal (nom) herein shall be accurate to within +/-500 ppm of the defined nominal value, unless specifically stated otherwise herein.

All time parameters of over-the-air transmissions from transponders stated as nominal shall be accurate to within +/-10% of the defined nominal value, unless specifically stated otherwise herein.

For conformance measurements of RF parameters specified herein the resolution bandwidth shall be 8 MHz minimum, unless specifically stated otherwise.

All specifications herein shall apply over the operating environment for the product (reader or transponder) and over the life of the product. The environmental specifications are the responsibility of the Group. For transponders the environmental requirements of SAE J1211 are recommended as a minimum.

The transponder shall operate on the principal of 'listen-before-talk'. This means the transponder shall only transmit information in response to a Trigger.

2.2 Spectrum Regulatory Requirements

The communications shall occur in a band allocated for vehicle identification and/or location applicable to the country of operation. For a device to be considered conformant to this protocol, it shall be conformant to the regulations of the country of operation.

- In the United States, the communications shall be carried out in and be conformant to the non-multilateration portion of the 902-928 MHz band allocated for Location and Monitoring Service, defined under Title 47, Part 90, Subpart M.
- In Canada, the communications shall be carried out in and be conformant to the non-multilateration portion of the 902-928 MHz band allocated for Location and Monitoring Service, defined under RSS-137.

2.3 Frequency

All reader transmissions shall be at a carrier frequency in the range 915.75 +/-0.203 MHz.

All transponder transmissions shall be at a carrier frequency in the range 914.3 to 915.5 MHz.

2.4 Polarization

Systems using this protocol shall operate using horizontal linear polarization where the reference plane is the surface on which the vehicle is travelling.

All transponders shall have horizontal linear polarization when mounted in or on vehicles according to the supplier mounting instructions.

All reader antennas shall have horizontal linear polarization.

2.5 Sensitivity

The transponder sensitivity is specified herein for interoperability. The reader requirements are outside the scope of this specification.

The transponder sensitivity is defined in units of field strength, where the field strength is measured at the transponder location when a vehicle is not present for a reader transmitting at the burst peak power of the reader.

The transponder sensitivity is the field strength level at which the transponder shall respond to Triggers and also the level at which the transponder shall be programmed. Increasing sensitivity denotes less field strength (i.e. the maximum sensitivity equates to a smaller field strength value than the minimum sensitivity). The following characteristics and requirements apply to the determination of sensitivity.

- The sensitivity is specified under conditions of the transponder mounted on vehicles in accordance with the transponder manufacturer's mounting instructions.
- At field strengths less than the maximum specified value of sensitivity the transponder shall not respond.
- At field strengths equal to or greater than the minimum specified value of sensitivity the transponder shall have a Read error rate and also a Program error rate no greater than 10^{-3}, i.e. the average number of times a Trigger, that is expected to produce a response, will not result in a Transponder Data transmission and also the number of times a Program Data operation, that is expected to succeed, will not succeed shall each on average be less than 1 in 1000. The average applies under each environment and test condition.
- The sensitivity limits apply at limits of a range of geometric angles which are defined relative to the surface on which the vehicle travels.
- Outside these geometric angle limits the specifications do not apply.
- Within the specified geometric angle range the field strength required for the transponder to respond shall always be less than or equal to the maximum value at the geometric angle limits (i.e. greater than or equal to that at sensitivity minimum).

Appendix 1 defines the specification of sensitivity by Tag Type (see Section 3.2.1).

2.6 Radiated Power

The transponder radiated power is specified herein for interoperability. The reader requirements are outside the scope of this specification.

The radiated power is defined as the effective instantaneous isotropic power (EIRP) at the burst peak power radiated in the direction of measurement. The following characteristics and requirements apply to the determination of radiated power.

- The radiated power is specified under conditions of the transponder mounted on vehicles in accordance with the transponder manufacturer's mounting instructions.
- The minimum radiated power limit applies at limits of a range of geometric angles that are defined relative to the surface on which the vehicle travels.
- Outside these geometric angle limits the specifications do not apply.
- Within the specified geometric angle range the radiated power shall always be equal to or greater than the minimum limit.

Appendix 1 defines the specification of transponder radiated power by Tag Type (see Section 3.2.1).

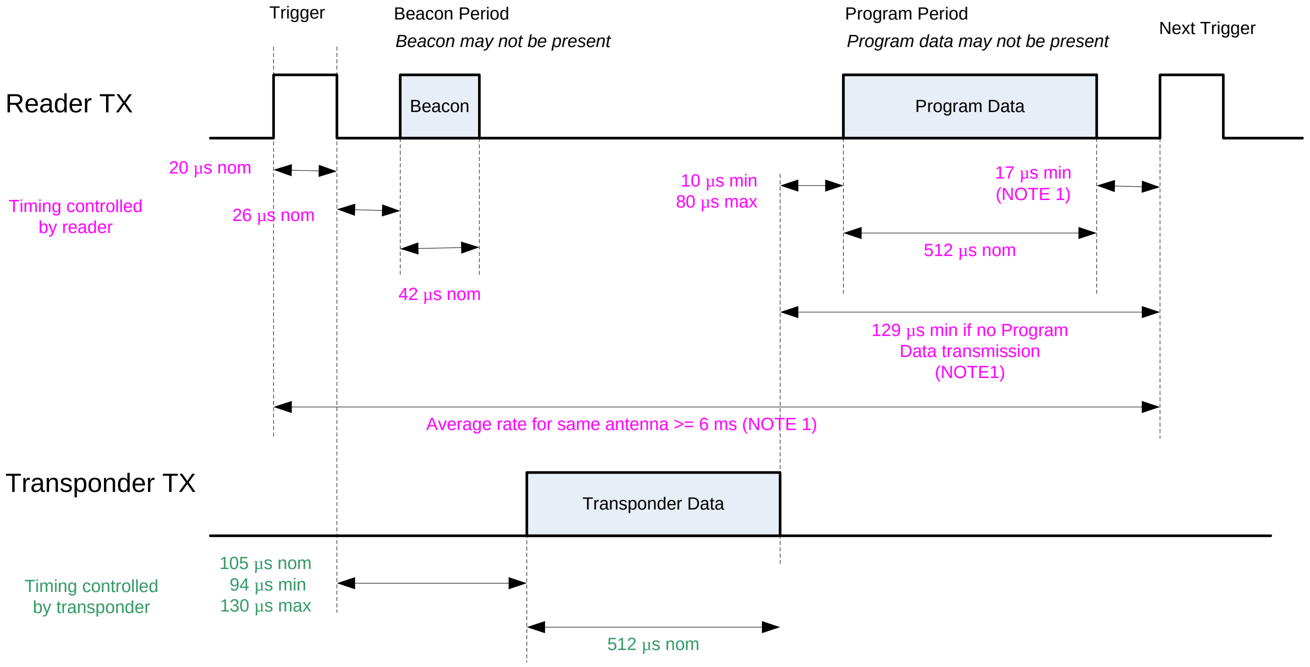
2.7 Transmission Timing

The protocol timing for an RF event shall conform to the timing defined in Figure 2-1.

The minimum spacing to the next RF event shall conform to that specified by that figure.

The timing of triggers in any instance of the protocol use shall be such that a transponder shall be triggered on average no faster than once every 6 ms per RF capture zone while it is within communication coverage for the site where the protocol is used.

Figure 2-1: Transmission Timing



NOTE 1 : The minimum timing to the next trigger is not intended to indicate that the triggers should be spaced at this timing. The average periodicity of triggers is separately specified.

2.8 Transmissions

The trigger shall be a single pulse of carrier frequency.

The Beacon transmission is optional on readers, but if present shall conform to the timing requirements specified herein. The Beacon transmitted by the reader shall be a 7 bit word specified in Section 3.1 and shall be transmitted MSB first. Reception of the Beacon is optional on transponders but all transponders shall meet the requirements of this Specification when a Beacon is present.

The Transponder Data transmitted by the transponder shall comprise of a 256 bit data structure specified in Section 3.2 and shall be transmitted MSB first.

The transmission of Program Data is optional. The Program Data transmitted by the reader shall comprise of a 256 bit data structure specified in Section 3.2 and shall be transmitted MSB first.

Note that the spectral emission requirements in the referenced regulatory requirements are applicable.

2.9 Modulation

All transmissions shall be ON-OFF keyed (OOK) amplitude modulation.

The OFF Isolation for the reader transmissions shall be 35 dB minimum.

The OFF Isolation for the transponder transmissions shall be 30 dB minimum.

The OFF Isolation applies outside 2 µs before a trigger pulse and before start of the first bit period of a beacon or data transmission and 2 µs after the end of the pulse and after the end of the last bit period of a beacon or data transmission.

2.9.1 Trigger Pulse Modulation

Each Trigger shall conform to the requirements of Table 2-1.

The Transponder shall not respond to pulses that have greater than 30 µs pulse width[1].

Table 2-1: Trigger Modulation

Parameter	Required Performance
Ideal ON Time	20 µs nom
Pulse Flatness	1 dB (see Figure 1-5)
Modulation Depth	25 dB (see Figure 1-5)
Pulse Width Variation	The pulse width deviation from ideal shall not exceed +/- 350 ns over the Modulation Depth

2.9.1 Beacon Modulation

The modulation specifications for the Beacon transmission that shall be met are provided in Table 2-2.

Table 2-2: Beacon Modulation

Parameter	Required Performance
Ideal Bit Rate	$166.\overline{6}$ kbps (6 µs bit period)
Bit Rate Tolerance	+/-500 ppm
Modulation	OOK Beacon (see Section 1.3.7)
Burst Flatness	As per Program Data Modulation
Pulse Flatness	
Modulation Depth	
Modulation Width Variation	

2.9.2 Transponder Data Modulation

The modulation specifications for the Transponder Data transmission that shall be met are provided in Table 2-3.

Table 2-3: Transponder Data Modulation

Parameter	Required Performance
Ideal Bit Rate	500 kbps (2.0 µs period)
Bit Rate Tolerance	+/-10%
Modulation	OOK Manchester (see Section 1.3.6)
Burst Flatness	1 dB peak-peak maximum
Pulse Flatness	1.5 dB peak-peak maximum
Modulation Depth	25 dB minimum
Modulation Width Variation	Maximum +/- 350 ns deviation from ideal values

---

[1] Required to prevent the transponder from erroneously responding to other protocols.

2.9.3 Program Data Modulation

The modulation specifications for the Program Data transmission that shall be met are provided in Table 2-4.

Table 2-4: Program Data Modulation

Parameter	Required Performance
Ideal Bit Rate	500 kbps (2.0 µs period)
Bit Rate Tolerance	+/- 500 ppm
Modulation	OOK Manchester (see Section 1.3.6)
Burst Flatness	2 dB peak-peak maximum
Pulse Flatness	1.5 dB peak-peak maximum
Modulation Depth	27 dB minimum
Modulation Width Variation	maximum +/-350 ns relative to ideal values

3. DATA LAYER SPECIFICATIONS

In the context of this protocol, communication to and from the data in the transponder memory that is accessible to a reader is treated as a 256-bit data structure that is organized as shown in Figure 3-2 and detailed in Section 3.2.

The Beacon is intended to transmit generic reader site information that the transponder application layer can use, principally for sites where high-occupancy vehicle (HOV) or high-occupancy toll (HOT) operations are required. In a Read cycle the transponder shall output its reader accessible memory in the Transponder Data transmission in accordance with the data structure defined in Figure 3-2.

The Program operation is intended to be used to modify the Reader Programmable portion of the transponder memory. The Program operation is optional on readers, but if present must conform to the requirements herein. All transponders shall support the Program operation and have a write-able portion of data memory.

For a Program operation the reader shall transmit the data to be programmed to the transponder in the Program Data transmission in accordance with the data structure defined in Figure 3-2 in accordance with the rules specified in Section 3.3. The transponder shall accept the Program Data in accordance with the rules specified in Section 3.3.

3.1 Beacon

The Beacon shall be organized as a 7-bit word in accordance with Figure 3-1. The fields comprising the word shall be set according to the following.

Figure 3-1: Beacon

Bit Number	6	5 ……. 3	2 ……. 1	0
	HO	Channel	RFU	Parity

Data is shown from most-significant bit on left to least significant bit on right

The HO bit shall indicate whether or not the RF capture zone for the reader antenna transmitting the Beacon is associated with a lane in which transponders of Tag Type HOV/HOT (see Section 3.2.1) to which application specific HOV/HOT rules apply. If the HO bit is set to 1, then the transponder shall interpret the RF capture zone as being one in which such rules apply. Note that the application specific rules are defined external to this protocol specification.

The bits in the Channel field shall contain a numeric value that shall be set by the reader according to the following rules:

- The value of Channel shall be different between antennas that have over-lapping RF capture zones and for each case of a transponder transaction for the antennas from which the transponder receives during the transponder transaction.
- The value of Channel transmitted on any antenna with which a transponder is conducting a transaction shall not be changed during the transponder transaction.

The RFU bits are reserved for future use. These bits shall be set to 00_B for all transmissions conformant to this protocol at the current revision.

The Parity bit is intended to provide a means of error checking the Beacon transmission by the transponder. The Parity bit shall be set to obtain odd parity over the entire Beacon word. An example of a valid word is 0000001_B.

3.2 Transponder Data

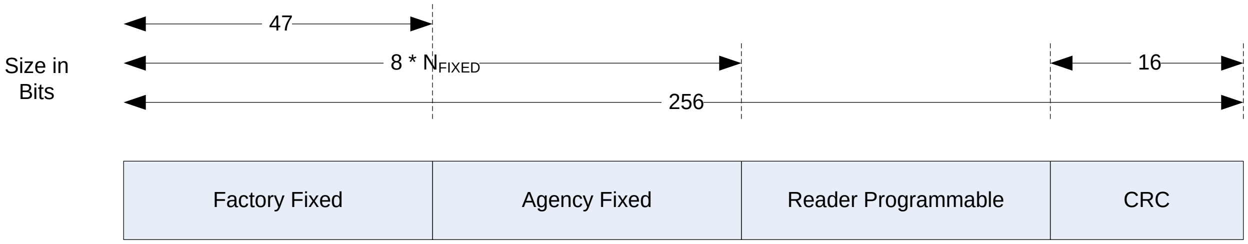
The transponder data that can be accessed by this protocol shall be accessed as a single 256-bit data structure organized in accordance with Figure 3-2. The data fields are defined in the following sections.

The transponder memory consists of a section that is locked, i.e. the content is fixed and cannot be changed by protocol, and the remainder can be changed by this protocol.

The portion of the transponder memory that is locked comprises the Factory Fixed and Agency Fixed data fields. The combined length of these fields is an integer number of bytes such that the length in bits can be expressed in the form 8 * N_{FIXED}.

The value of N_{FIXED} is set by the Group associated with the Group ID contained within the Factory Fixed portion of the transponder memory. All transponders with the same Group ID shall have the same value for N_{FIXED}.

Figure 3-2: Transponder Data Structure



Data is shown from most-significant bit on left to least significant bit on right

3.2.1 Factory Fixed

The Factory Fixed data field contains those portions of Transponder memory that shall be fixed and locked in the transponder memory at time of transponder manufacture. The Factory Fixed data shall be organized as defined by Figure 3-3. The individual fields of the Factory Fixed are defined in the following.

Figure 3-3: Factory Fixed

Bit Number	46 … 44	43 … 41	40 … 38	37 ……. 31	30 ….. 24	23 ……. 0
	Header	Tag Type	Application ID	Group ID	Agency ID	Serial Number

Data is shown from most-significant bit on left to least significant bit on right

The Header shall be 3 bits in length and shall be set to either 110_B or 111_B.

The Tag Type shall be 3 bits in length and shall be set according to the characteristics and intended placement of the transponder on a vehicle as defined by Table 3-1. More detail about the characteristics and intended placement is provided in Appendix 1: Tag Type Definitions. Control and maintenance of the valid list of Tag Types resides with the owner of this specification.

Table 3-1: Tag Type

Tag Type Value	Definition
0	Standard windshield mount transponder
1	Roof mount transponder
2	External mount transponder
3	Data specific windshield mount transponder
4	Commercial vehicle windshield mount transponder
5	HMI windshield mount transponder
6	HOV/HOT windshield mount transponder
7	Other tag type, encoded in Agency Fixed data field

The Application ID shall be a 3 bit word and shall be set in accordance with the intended use of the transponder as defined in Table 3-2. Control and maintenance of the valid list of Application ID resides with the owner of this specification.

Table 3-2: Application ID

Application ID value	Definition
0	Reserved for units for test
1	Toll Collection
2 - 7	Reserved for future use

The Group ID shall be 7 bits in length and shall be used to identify the Group to which the transponder is associated and for whom the transponder is manufactured. Assignment and maintenance of the valid list of Group ID and the identification of the contact organization for the Group resides with the owner of this specification.

The Agency ID shall be 7 bits in length and shall be used to identify the Agency within the Group to which the transponder is associated and for whom it was manufactured. Assignment and maintenance of the valid list of Agency ID resides with the contact organization for the Group identified by the Group ID stored in the transponder memory. Groups shall manage Agency ID assignment to ensure the uniqueness of transponder identification.

The Serial Number shall be 24 bits in length and shall be used to identify individual transponders associated with the Agency identified by the combination of the Group ID and Agency ID stored in the transponder memory. Assignment and maintenance of the valid list of Serial Numbers resides with the Agency identified by the combination of the Group ID and Agency ID stored in the transponder memory. Agencies shall manage Serial Number assignment to ensure the uniqueness of transponder identification, so that the combination of Group ID + Agency ID + Serial Number uniquely identify an instance of transponder manufacture.

3.2.2 Agency Fixed

The Agency Fixed data field contains those portions of transponder memory that are set by the Agency and cannot be changed by readers using this protocol. The organization and definition of content of this field lies outside the scope of this specification and resides with the contact organization for the Group identified by the Group ID contained within the transponder memory.

3.2.1 Reader Programmable

The Reader Programmable data field contains those portions of transponder memory that can be modified by readers using the protocol defined herein. The Reader Programmable field shall be organized into 3 data fields as defined by Figure 3-4.

Figure 3-4: Reader Programmable

Bit Number	N_{PROG} …… 48	47 ……. 40	39 ……. 0
	Programmable Block 1	HOV & Feedback	Programmable Block 2

Data is shown from most-significant bit on left to least significant bit on right

The organization and definition of content of the Programmable Block 1 and Programmable Block 2 fields lies outside the scope of this specification and resides with the Agency identified by the combination of the Group ID and Agency ID contained within the transponder memory.

For transponders with Tag Type values other than 5 or 6 (HMI and HOV/HOT), the organization and definition of content of the HOV & Feedback field lies outside the scope of this specification and resides with the Agency identified by the combination of the Group ID and Agency ID contained within the transponder memory.

For transponders with Tag Type value of 5 or 6, the HOV & Feedback field shall be organized as per Table 3-3. The application rules for the bit content and specific application, HMI and device characteristics are outside the scope of this Specification.

Table 3-3: HOV & Feedback

Bit number within Field	Definition for Tag Type value 5	Definition for Tag Type value 6
0	Reserved for future use	HOV/HOT enforcement bit written by reader
1	Reserved for future use	HOV/HOT declaration by the transponder. This bit shall not be changed by the reader.
2-3	A 2 bit value to control the visual feedback issued for the HMI event.	
4-5	A 2 bit value to control the audio feedback issued for the HMI event.	
6	Reserved for future use	If this bit content is changed by a Program operation, it shall trigger a HOV specific HMI operation on the transponder on end of the transaction (see Figure 1-4)
7	If this bit content is changed by a Program operation, it shall trigger a HMI operation on the transponder at the end of the transaction (see Figure 1-4).	

3.2.2 CRC

The transponder memory and transmission of Transponder Data is protected against error by a 16-bit cyclic redundancy checksum. The checksum shall be generated according to the following:

- The checksum generator shall use the polynomial $x^{16} + x^{12} + x^5 + 1$.
- The checksum generator shall be preset to 0000_H.
- The data shall be supplied to the checksum generator starting with the MSB of the 256-bit data structure and include all data bits of the fields except the CRC field.
- The residue in the checksum generator shall be used for the CRC field.

The checksum can be verified using the following or an equivalent.

- The checksum generator will use the polynomial $x^{16} + x^{12} + x^5 + 1$.
- The checksum generator will be preset to 0000_H.
- The entire 256-bit data structure will be supplied to the checksum generator starting with the MSB and ending with the LSB.

- The checksum will be considered valid if the residue in the checksum generator after this operation is $0000_{H.}$

3.3 Program Rules

A reader shall only attempt to program a transponder if the reader has permission to program the Group ID. Permissions lie outside the scope of this Specification and relate to agreements between Groups.

A reader shall program the transponder according to the data content and organization specified by the Group identified by the Group ID in the transponder memory.

A transponder shall only change the Reader Programmable portion of its memory when the Program Data it receives conforms to the following:

- The N_{FIXED} most significant bytes of the data in the Program Data exactly match the N_{FIXED} most significant bytes of the data currently in transponder memory.
- The CRC on the Program Data is correct, as defined in Section 3.2.2.

When the transponder changes the Reader Programmable portion of its memory, it shall also change the CRC to match.

The changes of the transponder memory due to receipt of valid Program Data shall be implemented within the minimum time to the next trigger as specified in Figure 2-1.

The N_{FIXED} most significant bytes of the data in transponder memory shall not be changed by a Program operation.

4. APPENDIX 1: TAG TYPE DEFINITIONS AND SPECIFIC REQUIREMENTS

There are 3 basic categories of transponder defined in this specification:

- A windshield mount transponder is intended to be mounted inside or outside the vehicle near or attached to the windshield. A number of specific Tag Type variants of windshield mount transponder exist and these are categorized according to Table 4-1.
- An external mount transponder is intended to be mounted on the front-end of a vehicle
- A roof mount transponder is intended for mounting on top of the cab of a commercial vehicle.

The above should be used as guidelines for encoding Tag Type into a transponder.

Table 4-1: Specific Windshield Transponder Categorization

Type	Definition
Commercial	The transponder specifically for use in commercial vehicles only and has specific characteristics different to a standard windshield mount transponder. These specific characteristics lie outside the scope of this specification.
Data Specific	The transponder reader programmable content contains data that requires the program data to be tag specific, and generally requires the reader to receive tag specific data from a higher level system (e.g. toll back office) to determine the information to write.
HMI	The transponder has an audio and/or visual feedback to the driver that is activated by a Program operation modifying the HOV & Feedback field as defined herein.
HOT/HOV	The transponder has a means for the driver to change the HOT/HOV declaration bit in the HOV & Feedback field of the transponder memory. The transponder may also have audio and/or visual feedback to the driver that is HOV specific.

When mounted on vehicles the geometric angles and RF communication link distances that occur when communicating with the readers differ for the three basic categories of transponder. Therefore the Sensitivity and Radiated Power requirements apply over a geometric angle range and when mounted on the vehicle.

Table 4-2 defines the performance requirements for the transponders that shall be met over environment and life

The geometric angle range is to be interpreted as follows.

- The origin for angles is the transponder location on the vehicle
- Elevation angle is the minimum angle subtended between a direction originating from the origin and a plane parallel to the travel surface at the transponder height, within which plane the origin lies, where the direction of vehicle travel lies in the plane and represents the angle zero, and increasing value of angle represents increasing direction above the plane.
- Azimuth angle is the minimum angle subtended between a direction originating from the origin and a plane normal to the travel surface, within which plane the origin lies, and where the direction of vehicle travel lies in the plane and represents the angle zero.
- The geometric range is defined as two separate angle ranges:
  - The elevation range, with azimuth angle zero.
  - The azimuth range, applied to at least one elevation angle within the elevation range.

Table 4-2: Sensitivity and Radiated Power Requirements at Vehicle

Tag mount type	Geometric Angle Range	Sensitivity over geometric range	Radiated Power at min Elevation, Azimuth 0	Radiated power over geometric range
Windshield	Elevation range from 54 to 92.6 degrees Azimuth range from -17.5 to 17.1 degrees	Minimum 0.83 V/m Maximum 2.60 V/m	Minimum -8.4 dBm EIRP	Maximum +7.5 dBm
External	Elevation range from 55 to 92 degrees Azimuth range from -17.2 to 17.2 degrees	Minimum 0.68 V/m Maximum 1.81V/m	Minimum -7.3 dBm EIRP	Maximum +7.5 dBm
Roof	Elevation range from 45.2 to 123.3 degrees Azimuth range from -29.5 to 29.5 degrees	Minimum 0.60 V/m Maximum 1.62 V/m	Minimum -7.7 dBm EIRP	Maximum +7.5 dBm

5. APPENDIX 2: EXHIBIT OF MINIMUM ARTICLES TO BE REQUIRED BY AGENCIES OR GROUPS AND ACCEPTED BY SUPPLIERS FOR SUPPLY OF PRODUCT CONFORMANT TO THIS SPECIFICATION

This will address the following:

- *Agree to only supply devices with Group IDs that they have contracted with such groups or agencies, and not to supply devices without such agreements.*
- *Agree to only supply devices with Agency IDs that they have contracted with such groups or agencies to such agencies, their representatives, or on behalf of such agencies*
- *Agree to uniquely serial number devices and only issue the serial numbers that the agencies have authorized.*
- *Agree to not modify the protocol or supply variants without agreement by Kapsch and any groups or agencies using the protocol.*
- *Agree to conform with the definitions of Tag Type defined in this specification.*
- *Agree to not assign Application IDs without agreement by Kapsch and any groups or agencies using the protocol.*
- *Agree to only supply product to purchasers that are authorized by such groups or agencies to receive them.*
- *Agree to conformance testing to the protocol and fit for purpose testing by agency/group.*
- *Agree to indemnify and hold harmless the Agency and Kapsch for any claims or damages of any nature against such supplier, its customers or its agents related to the specification.*

AGENCIES/GROUPS would need to agree (IBTTA or other forum) to:

- *Agree to singular control of Group ID issuing (Kapsch)*
- *Agree to require suppliers to conform to articles*
- *Agree to use only conformant equipment, and to test for fit-for purpose.*
- *Control serial number issuing*

Note similar requirements would apply to any protocol.